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ASSESSMENT OF SOIL LOSSES BY EPHEMERAL GULLY EROSION USING HIGH-ALTITUDE (STEREO) AERIAL PHOTOGRAPHS

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ABSTRACT

The objective of this study is to explore in a critical way the potential of high-altitude (stereo) aerial photographs for the assessment of ephemeral gully erosion rates. On 28 May 1995, an intensive rainfall event (30 mm h^{-1} during 30 min, return period = 3 years) occurred in central Belgium. Ephemeral gullies formed within an area of 218 ha (study area 1) were mapped and measured both in the field and by high-altitude aerial photos taken at the same time. Comparison of these two methods shows that if only one of the two surveying techniques had been used, only 75 per cent of the total ephemeral gully length would have been detected, so that the combination of aerial and field data leads, in fact, to the best possible determination of total gully length within the selected area. A correction factor (*C*) is proposed, so that the results of an ephemeral gully erosion survey based on high-altitude (stereo) aerial photos can be adjusted for the undetected gullies.

Next, a sequential series of high-altitude stereo aerial photographs, taken in six different years, was analysed in order to determine ephemeral gully erosion rates in three selected study areas (study areas 2, 3 and 4). Selection criteria were chosen so that these three areas were similar to study area 1 and representative for the cultivated areas in central Belgium where intense soil erosion regularly occurs. Ephemeral gullies were mapped and their total length was measured from the aerial photos. Using a mean gully cross-section of 0·2635 m^2 (determined in study area 1), the average eroded volume is 1·89 m^3 ha^{-1} in six months for study area 1, 0·86 m^3 ha^{-1} in six months for area 2, 1·44 m^3 ha^{-1} in six months for area 3, and 2·37 m^3 ha^{-1} in six months for area 4. According to the correction factor (*C*), these mean ephemeral gully erosion volumes have to be increased by 44 per cent. The ephemeral gully erosion rates based on high-altitude stereo aerial photos, correspond well with the results of other surveys carried out in the Belgian loess belt. Copyright © 1999 John Wiley & Sons, Ltd.

KEY WORDS: ephemeral gully erosion; Belgian loess belt; high-altitude stereo aerial photographs; field survey

INTRODUCTION

The recognition of ephemeral gully erosion as a separate erosion class is relatively recent (Foster, 1986). In the loess region of western Europe several researchers have already pointed to the importance of ephemeral gully erosion (e.g. Evans and Cook, 1987; De Ploey, 1990; Poesen and Govers, 1990; Papy and Douyer, 1991; Poesen *et al.*, 1996). However, many erosion studies, concerned with soil losses from arable land caused by rain and overland flow, still overlook the contribution of ephemeral gullying (Poesen *et al.*, 1998). This results mainly from the fact that the most used tool for assessing water erosion rates is the Universal Soil Loss Equation (USLE) and the USLE-derived models, which only count for interrill and rill erosion (Wischmeier and Smith, 1978). In fact there are a few erosion models, such as EGEM (Ephemeral Gully Erosion Model; Merkel *et al.*, 1988), CREAMS (Chemicals, Runoff and Erosion from Agricultural Management Systems; Knisel, 1980), GLEAMS (Groundwater Loading Effects of Agricultural Management Systems; Knisel, 1993) and WEPP (Water Erosion Prediction Project; Flanagan and Nearing, 1995), that do account for soil losses caused by ephemeral gullying. The instant applicability of these models is, however, often hindered by the

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nature of the required input parameters. For instance, in each of these models the exact topographical position of the gully has to be known before the model can be applied (Poesen *et al.*, 1998).

The combination of neglecting ephemeral gully erosion in many water erosion studies and of difficulties with estimating ephemeral gully erosion rates through the existing models stresses the need for further research on this topic.

A major problem with ephemeral gully erosion research is the collection of reliable data. The most obvious way to gather data on ephemeral gully erosion is by what can be called 'an after event field survey'. Immediately after a rainfall event, an area is surveyed in the field to locate and measure the characterizing parameters of ephemeral gullies. This method can result in fairly accurate data. But the area that can be covered is often very small due to the labour intensity of the method and the temporary nature of the ephemeral gullies (i.e. disturbance by farming operations, overgrowing by plants). From this point of view a sequential series of aerial photographs can be of great help in assessing ephemeral gully erosion rates, as they permit research to be extended in space and time.

Several researchers have already used aerial photos to assess soil erosion. Morgan *et al.* (1978, 1980), Morgan and Napela (1982) and Stephens *et al.* (1985) used high-altitude aerial photos (scale 1:60 000 and 1:120 000) in conjunction with the USLE and a computerized land information system to identify areas prone to erosion. Patton and Schumm (1975) determined gully positions from aerial photographs (scale 1:12 000) and plotted them on topographic maps in order to establish a relation between the drainage-basin area and the critical slope for entrenchment. Vandaele *et al.* (1996a) continued the work of Patton and Schumm, but tried to assess erosion volumes based on aerial photo data (scale: 1:15 000 to 1:21 000; Vandaele *et al.* 1996b). For this purpose mean gully cross-sections were estimated based on field measurements related to a similar area but to another rainfall event. Thomas *et al.* (1986) and Thomas and Welch (1988) used low-altitude aerial photos (scale: 1:750 to 1:2000) that were specifically taken to assess ephemeral gully erosion in their study area. This resulted in high quality data (i.e. ideal visibility, ideal timing), but the cost was high and consequently the extension in space was limited. Furthermore, the extension over time is also limited to the duration of the research period.

The objective of this paper is to investigate the potential of high-altitude stereo aerial photographs (HASAP) for the study of ephemeral gully erosion. Therefore, data from aerial photos will be compared with field data collected in the same study area at the same time. This comparison will let us compute a correction factor for the aerial photo data so that reasonable estimates of soil losses can be made for an extended area and extended time.

METHODS

The research carried out for this paper consists of two parts. In the first part, the calibration, data from aerial photographs are compared with field data for the same area and the same time. On 28 May 1995, an intense rainfall event hit the Belgian loess belt between Brussels and Leuven. Rain intensity was about 30 mm h^{-1} during 30 min. Such an event has a return period of *c.* 3 years (Laurent, 1976; Demarée, 1985). In June 1995 all ephemeral gullies formed in an area of about 218 ha (only arable land included) (area 1, Figure 1) were mapped and their length and cross-sectional area were measured in the field, so that eroded volumes for each gully could be calculated. About the same time (June 1995), aerial photos were taken over the study area. The photos were published in the *'Aero-atlas Vlaams Brabant en Brussel'* (Anon., 1996). They are coloured and printed on a scale of 1:10 000 (original photos have a scale of 1:30 000, format = 23 cm × 23 cm, focal length of camera (f) = 152 mm). From these aerial photographs all the visible ephemeral gullies within study area 1 were mapped and their length was measured.

As the ephemeral gullies observed in the field and on aerial photos were created by one and the same event, both data sets can be compared directly with each other. Not all gullies observed in the field were detected on the aerial photos because of the limited visibility. But some gullies that were observed on the aerial photos had not been seen in the field. This is due to the fact that some parts of the study area had high-standing vegetation (corn or wheat), which hid some ephemeral gullies from a terrestrial viewpoint, but not from an aerial viewpoint. The comparison and combination of aerial and field data leads to 'the best possible

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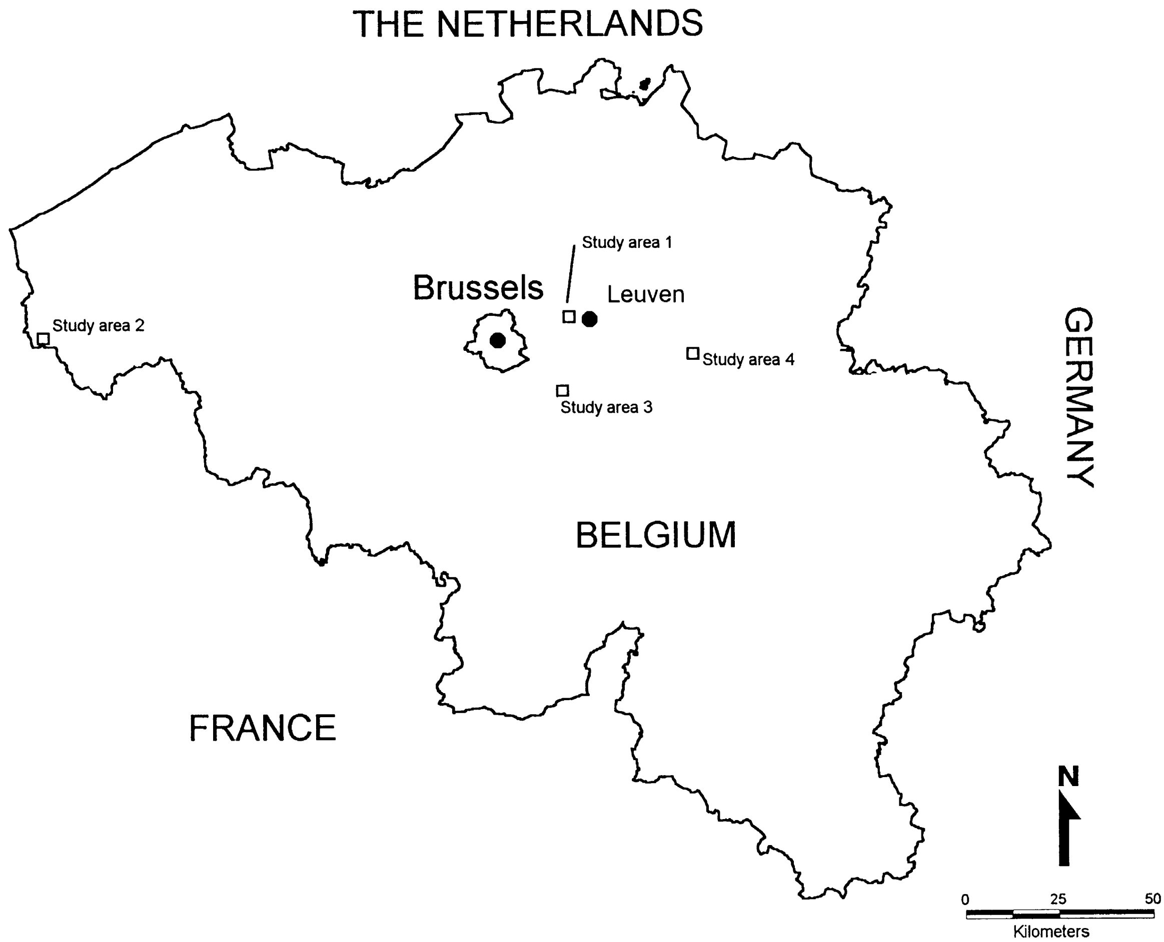

Figure 1. Map showing the location of the study areas 1, 2, 3 and 4

determination' of total ephemeral gully length within the selected study area; only the gullies invisible on the aerial photos and overlooked during the field survey are not accounted for. Based on this 'best possible determination' of total ephemeral gully length, a correction factor to adjust the aerial photo data to 'the best possible determination' can be set up.

In the second part, the exploitation, three study areas were selected (study areas 2, 3 and 4, Figure 1). The three areas are about the same size: area 2 = 861 ha, area 3 = 1095 ha, and area 4 = 889 ha (woodland and pasture excluded). The area of cultivated land in the three study areas was determined from a topographical map, representing the situation in 1988 for study area 1, 1981 for study area 2 and 1995 for study area 3. Although the ratio between cultivated land and woodland and pasture may have varied over time, a fixed area in each study area was used for reasons of simplicity. Selection criteria for the study areas were chosen so that the areas were representative for the cultivated areas in central Belgium where intense soil erosion regularly occurs. Consequently, the three study areas are similar to study area 1. Study areas 1, 3 and 4 are part of the Belgian loess belt, which is characterized by a semicontinuous loess cover. The depth of loess varies, but is of the order of a few centimetres to 10 m (Goossens, 1991). Topsoil has a high silt content (70–80 per cent), a clay content of 10–20 per cent and a sand content below 15 per cent (Govers, 1991). Area 2 is located on the northern border of the Belgian loess belt. This area is somewhat more sandy (Hubert, 1962). With respect to topography, the difference between the highest and the lowest point in each of the study areas can be used as

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Table I. Characteristics of the high-altitude stereo aerial photos (HASAP) of study areas 2, 3 and 4

Year	Date	Scale
Study Area 2		
1952	17 Apr	1/25 000
1959	11 Sep	1/28 000
1973	27 Apr	1/18 500
1985	4 Jun	1/21 000
1988	14 May	1/21 000
1996	5 Jun	1/20 500
Study Area 3		
1947	23 Jun	1/20 000
1952	14 May	1/20 000
1969	11 Jun	1/18 500
1980	12 May	1/21 000
1985	1 Oct	1/21 000
1990	3 May	1/21 000
Study Area 4		
1947	29 Aug	1/20 000
1957	5 Apr	1/28 000
1975	20 May	1/18 500
1983	29 Sep	1/21 000
1989	21 Jun	1/21 000
1996	27 Mar	1/20 500

an indicator of the relief intensity. Maximum height differences are 32·5 m for study area 1, 36 m for study area 2, 21·5 m for study area 3 and 42 m for study area 4. Mean annual precipitation amounts to 814 mm for area 1, 700 mm for area 2, 774 mm for area 3 and 713 mm for area 4 (KMI, 1996).

The research for the exploitation part is based on the use of the standard HASAP of the National Geographic Institute of Belgium. These photos, which have a nominal scale of 1:21 000 (range 1:18 500–1:28 000, $f = 152$, format = 23 cm $\times$ 23 cm or 13 cm $\times$ 18 cm, overlap 60 per cent), have been taken at regular intervals to update the Belgian topographical maps.

A sequential series of HASAP (i.e. all aerial photos available) was acquired for each of the study areas 2, 3 and 4. For these areas, this sequential series consists of six different photographs taken during a period from 1947 to 1997 (Table I). From these HASAP, the gully pattern was mapped by means of a stereoscope (Wild ST4, magnification $\times$3). Lines on the HASAP were classified as ephemeral gullies if there was clear evidence for it (e.g. a sedimentation fan at the end of the line or the line is lying in a clearly defined hollow). The visibility of the ephemeral gullies on the aerial photos depends on many factors, such as the width of the gully, the contrast of the gully with respect to its direct environment, the resolution and the contrast of the photo. Experience shows that gullies with a width between 0·5 m and 1 m can be observed on both the aerial photos of the *Aero-atlas Vlaams Brabant en Brussel* (Anon., 1996) and the HASAP from the National Geographic Institute of Belgium.

All the observed gullies were digitized using Tosca/Idrisi (Jones, 1991). The total length of the ephemeral gullies was computed using the Mapinfo software package (Mapinfo Professional Version 4·0). Figure 2 illustrates the location of ephemeral gullies in study area 4, as determined from the sequential series of aerial photos for that area. Woodland and pasture, as indicated on the maps, represent the situation in 1995, which explains the occurrence of ephemeral gullies within woodland and pasture areas for 1947 and 1957. From these maps, ephemeral gully density values were calculated. As for the Belgian National Geographic Institute, the weather conditions are the only factor determining whether or not aerial photographs are taken; a sequential series of aerial photos represents a random sample for a certain area. Therefore, calculated ephemeral gully densities may be assumed to represent mean values for the given area. Furthermore,

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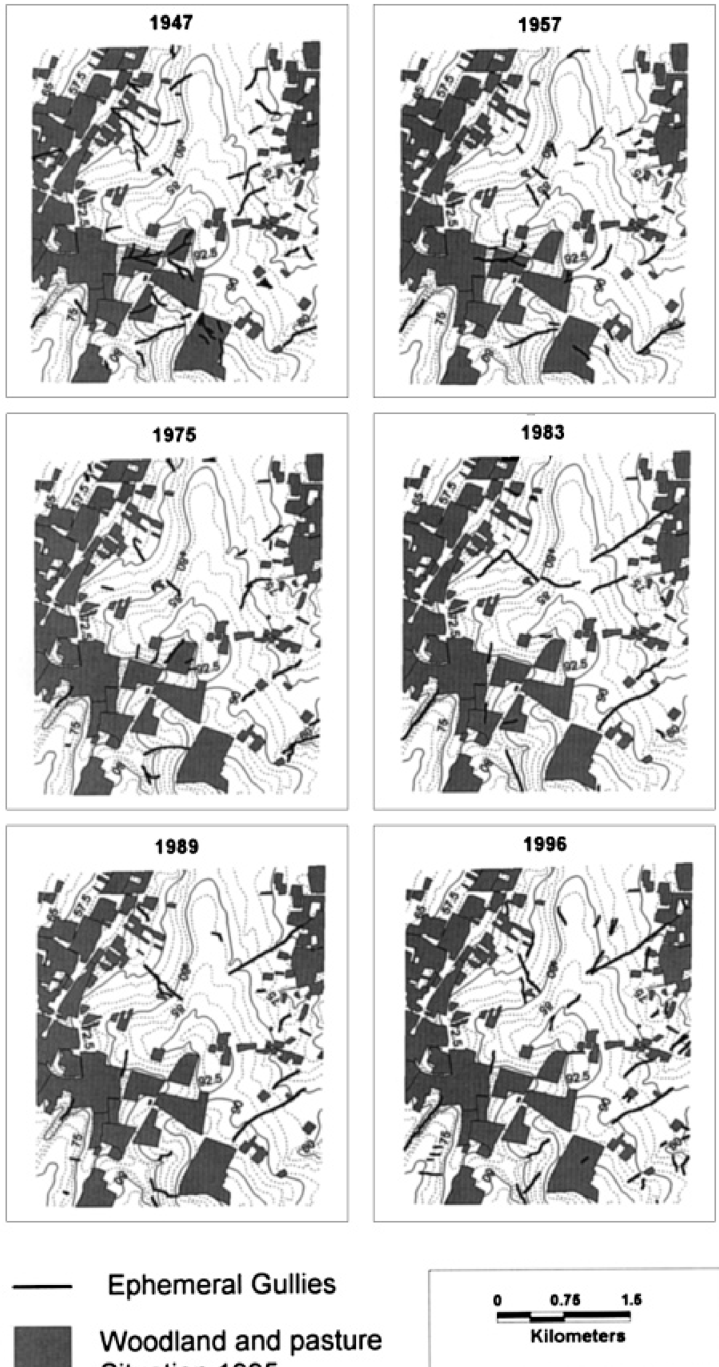

Figure 2. Maps showing the location of the ephemeral gullies of study area 4, as observed from a sequential series of high-altitude stereo aerial photos

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Table II. Ephemeral gully erosion data for study area 1 obtained by field surveys and by analysis of high-altitude aerial photos

	Aerial photographs	Field
Number of gullies	18	23
Gully length (m)	1558	1722
Gully density (m ha^{-1}	7·1	7·9
Length of gullies seen in the field and on the aerial photos		**1026 m** (13 gullies)
Length of gullies observed in the field and not on the aerial photos (because the gullies were too small (58 m; four gullies) or because gullies formed in a linear landscape feature (588 m; six gullies)		**646 m** (10 gullies)
Length of gully segment seen in the field and not on the aerial photos (because gully segment was filled up)		**50 m** (1 segment)
Length of gullies observed on the aerial photos and not in the field		**520 m** (5 gullies)
Length of gully segment seen on the aerial photos and not in the field (because gully segment was incorrectly classified)		**12 m** (1 segment)
Total length of gullies observed		**2254 m**
True total length of gullies observed (= 2254 − 12 m)		**2242 m**

ephemeral gullies represented on these photos are formed between the last tillage pass and the date of taking the aerial photograph. This means that they developed over a time span with a maximum of six months.

In order to transform the ephemeral gully density values to eroded volumes, information about the cross-sections of the gullies is required. Since we do not have any information about the situation in the field at the time when the HASAP were taken, mean depth and width values from the gullies of study area 1 will be used to calculate eroded volumes.

RESULTS

Calibration

Table II shows the results for study area 1. Only 13 gullies, with a total length of 1026 m, were observed both in the field and on the aerial photographs. Of these 13 gullies, one gully was only partially observed on the aerial photo because it had been filled up by the farmer over a length of 50 m, while another gully was measured to be 12 m longer on the aerial photos because the sedimentation zone could not be discerned from the gully itself. All other gullies had the same length when measured in the field as when measured from the aerial photos.

Ten gullies, representing a total gully length of 646 m, were only observed during the field survey. Out of these 10 gullies, four were too small to be seen from the aerial photo (gully width $< 0·5$ m). The six other gullies were located in linear landscape features such as parcel borders and dead furrows and could not be distinguished from an ungullied linear landscape feature on the aerial photos (Figures 3, 4 and 5). In terms of gully length, the first group of four gullies is not of great importance (58·1 m), but the other gullies which had not been recognized on the aerial photos have a combined total length of 587·9 m.

Five ephemeral gullies, with a total length of 520 m, were only observed on the aerial photos. It may be surprising that there are gullies which were overlooked during field work. But at the time of the field work (June 1995) crops such as corn and wheat were almost at their maximum size, and as each of these five gullies was entirely located within one parcel, it is not surprising that gullies, totally surrounded by high-standing crops, were overlooked.

The 'best possible estimate' of the total ephemeral gully length within area 1 can now be made by combining the field observations with the observations from the aerial photos. The length of the gullies seen

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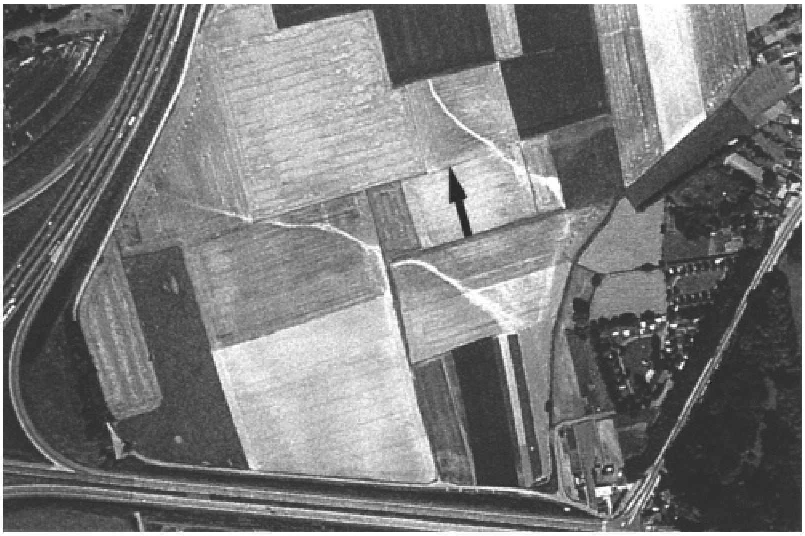

Figure 3. Aerial photo taken in June 1995, clearly showing two ephemeral gullies in study area 1. The uppermost gully (also shown in Figure 4) has a total length of 135 m. The arrow points to a dead furrow located in a parcel border, in which a third ephemeral gully (also shown in Figure 5) is located

Figure 4. Photo showing the uppermost ephemeral gully from Figure 3. This gully, which developed in a corn field, has a width of about 3 m and a depth ranging from 0·10 to 0·15 m (depth corresponds to depth of last tillage pass)

both in the field and on the photos (1026 m) must be increased by the length of the gully segment that was filled up (50 m), the length of the gullies only seen in the field (646 m) and the length of the gullies only observed on the aerial photographs (520 m). Total ephemeral gully length measured in area 1 then equals 2242 m. If only one of the two surveying techniques had been used, not more than 69 per cent (for the aerial photos) or 74 per cent (for the field survey) of the total ephemeral gully length would have been measured.

The unique combination of field data and aerial photo data for the same study area and the same event, allows one to calculate a correction factor (C). This correction factor permits the results of the ephemeral

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Figure 5. Photo showing an ephemeral gully located in a dead furrow coinciding with a parcel border (see arrow on Figure 3). Maximum gully depth is about 1·6 m, and mean gully width is about 0·8 m

gully erosion survey based on aerial photographs to be adjusted for the gullies that are invisible on the photos:

$$C_{\text{aerial photo}} = \frac{\text{True total length of gullies}}{\text{Total length of gullies observed on the aerial photo}} = \frac{2242\text{ m}}{1558\text{ m}} = 1\cdot 44$$

Although this correction factor is time and space specific, it reflects the error on the assessment of the ephemeral gully length via HASAP for a typical rainfall event in a typical agricultural area in central Belgium. Note that if only field work is carried out, the error will be somewhat less (i.e. $C_{\text{field}} = 1\cdot 30$).

Exploitation

Table III shows the results of the ephemeral gully erosion survey based on the analysis of HASAP. The number of gullies, the total gully length and the gully density were directly derived from the HASAP. Gully erosion volumes were calculated using a mean cross-section value determined for the ephemeral gullies of study area 1. Table IV summarizes the cross-section measurements for 43 ephemeral gullies (170 gully sections) of study area 1. Width, depth and cross-section measurements for each gully were weighted by length. From these weighted averages the minimum, the maximum and the mean values are shown in Table IV. Again, the mean value is a weighted average with the length of the respective ephemeral gullies as the weighting factor. The mean cross-section for the ephemeral gullies in study area 1 is then $0\cdot 26\text{ m}^2$, with $0\cdot 18\text{ m}^2$ and $0\cdot 35\text{ m}^2$ (respectively the mean +/− the standard deviation) as reasonable upper and lower limits.

Values of soil loss (Table III) due to ephemeral gully erosion are obtained by multiplying the gully erosion volume by the mean bulk density of the topsoil ($Bd = 1\cdot 3$ ton m^{-3}; Govers and Poesen, 1985). Soil loss rates are expressed in tons per hectare in 6 months, as the maximum period between the last tillage pass and the taking of the HASAP was estimated to be 6 months.

The mean ephemeral gully erosion rates for the three study areas show clear differences. The more sandy soil in study area 2 might (partially) explain the lower eroded volumes, whereas the higher eroded volumes in study area 4 could be related to the higher relief intensity in that area. However, this is only hypothetical and

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Table III. Ephemeral gully erosion data for study areas 2, 3 and 4, extracted from high-altitude aerial photographs. The mean gully cross-section used for calculating gully volumes is 0·26 m^2. For the lower and upper estimate of gully volumes a gully cross-section of 0·18 m^2 and 0·35 m^2 is used, respectively (see Table IV). Dry topsoil bulk density used in calculations equals 1300 kg m^{-3}

				Estimate of ephemeral gully erosion volume (m^3 ha^{-1} in 6 months)			Estimate of soil loss (ton ha^{-1} in 6 months)		
Year	Number of gullies	Total gully length (m)	Gully density (m ha^{-1})	Mean	Lower	Upper	Mean	Lower	Upper
Study area 2 (861 ha)									
1996	31	3400	3·9	1·04	0·70	1·39	1·35	0·90	1·80
1988	25	2000	2·3	0·61	0·41	0·82	0·80	0·53	1·06
1985	38	3400	3·9	1·04	0·70	1·39	1·35	0·90	1·80
1973	16	1800	2·1	0·55	0·37	0·73	0·72	0·48	0·95
1959	28	3200	3·7	0·98	0·65	1·30	1·27	0·85	1·70
1952	17	3100	3·6	0·95	0·63	1·26	1·23	0·82	1·64
Mean	**26**	**2800**	**3·3**	**0·86**	**0·57**	**1·14**	**1·11**	**0·74**	**1·48**
Study area 3 (1095 ha)									
1990	31	6700	6·1	1·61	1·08	2·15	2·10	1·40	2·79
1985	68	9800	8·9	1·52	1·01	2·02	3·07	2·05	4·08
1980	32	6300	5·8	2·36	1·58	3·14	1·97	1·32	2·62
1969	33	4700	4·3	1·13	0·76	1·51	1·47	0·98	1·96
1952	17	2800	2·6	0·67	0·45	0·90	0·88	0·59	1·17
1947	47	5600	5·1	1·35	0·90	1·79	1·75	1·17	2·33
Mean	**38**	**6000**	**5·5**	**1·44**	**0·96**	**1·92**	**1·88**	**1·25**	**2·50**
Study area 4 (889 ha)									
1996	43	10 500	11·8	3·11	2·08	4·14	4·05	2·70	5·39
1989	17	5700	6·4	1·69	1·13	2·25	2·20	1·47	2·92
1983	21	7200	8·1	2·13	1·43	2·84	2·77	1·85	3·69
1975	41	6100	6·9	1·81	1·21	2·41	2·35	1·57	3·13
1957	34	6600	7·4	1·96	1·31	2·61	2·54	1·70	3·39
1947	66	11 800	13·3	3·50	2·34	4·66	4·55	3·04	6·05
Mean	**37**	**8000**	**9·0**	**2·37**	**1·58**	**3·16**	**3·08**	**2·06**	**4·11**

Table IV. Average gully cross-section data collected in study area 1

	Minimum	Maximum	Mean*	St. dev.
Average†width (cm)	90	700	**210**	104
Average†depth (cm)	2	44	**16**	8
Average†cross-section (cm^2)	720	4528	**2635**	874

* Mean for all gullies, weighted by the length of the respective ephemeral gullies ($n = 43$)
† Average per gully, weighted by the length of the respective ephemeral gully sections ($n = 170$)

several other factors such as rainfall intensity, crop type or date of taking of the HASAP can be responsible for the observed differences.

The values from Table III can be corrected for the invisible and the incorrectly classified gullies, using the correction factor C ($C_{\mathrm{aerial\ photo}} = 1{\cdot}44$). Table V shows the corrected average figures for each of the three areas. Again, a mean, a lower and an upper estimate are given. The assumption made of course, is that this factor (C) is constant through space and time. Although there is no direct evidence for this assumption, indirect evidence can be obtained by comparing the results of the aerial photo gully survey with results from similar surveys described in the literature and results from other ephemeral gully surveying techniques (Table VI).

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Table V. Adjusted mean gully erosion data for study areas 2, 3 and 4. Data of Table III are multiplied by the correction factor (C = 1·44), so that the invisible gullies and the incorrectly classified gullies on the aerial photographs are taken into account

	Adjusted estimate of ephemeral gully erosion volume (m^3 ha^{-1} in 6 months)			Adjusted estimate of soil loss (ton ha^{-1} in 6 months)		
	Mean	Lower	Upper	Mean	Lower	Upper
Study area 2	**1·24**	0·82	1·64	**1·60**	1·07	2·13
Study area 3	**2·07**	1·38	2·77	**2·70**	1·80	3·60
Study area 4	**3·41**	2·28	4·55	**4·44**	2·97	5·92
Mean	**2·24**	1·50	2·99	**2·92**	1·95	3·88

Table VI. Comparison of several ephemeral gully erosion surveys carried out in central Belgium

Method of surveying	Size of study area (ha)	Number of observation periods	Duration of one observation period, I	Ephemeral gully erosion (m^3 ha^{-1} T^{-1})	Adjusted ephemeral gully erosion (m^3 ha^{-1} T^{-1})	Source
Field mapping	50	3	1 year	2·7		Vandaele and Poesen (1995)
Field mapping	110	3	1 year	2·5		Vandaele (1997)
Field mapping	210	3	1 year	0·8		Vandaele (1997)
Field mapping	218	1	0–6 months*	1·6		Study area 1
Aerial photos	1062	3	0–6 months†	1·2–2·4‡		Vandaele *et al.* (1996b)
Aerial photos	218	1	0–6 months*	1·3–2·5‡	1·9–3·6‡	Study area 1
Aerial photos	861	6	0–6 months†	0·6–1·1‡	0·9–1·6‡	Study area 2
Aerial photos	1095	6	0–6 months†	1·0–1·9‡	1·4–2·7‡	Study area 3
Aerial photos	889	6	0–6 months†	1·6–3·2‡	2·3–4·6‡	Study area 4

* After event field survey. Gullies formed during one extreme event (28 May, 1995)
† Ephemeral gullies formed between last tillage pass and taking of the high-altitude (stereo) aerial photo (0–6 months)
‡ Two cross-sections used 0·18 m^2 and 0·35 m^2

From Table VI, it is clear that the ephemeral gully erosion values for our study areas fit reasonably well with those obtained from different but very similar areas in central Belgium. It must be remarked that for the data based on aerial photos, uncorrected values are used. Corrected figures would be more logical but less straightforward, as the other data might need a correction too. For the data obtained by Vandaele *et al.* (1996b) the same correction factor could be used, but for the results of the field work, it is difficult to propose one single correction factor. Moreover, the results of Vandaele and Poesen (1995) and Vandaele (1997) probably do not need a correction factor. Their study areas are quite small and have been studied during three consecutive years, so that it can be expected that the probability of overlooking an ephemeral gully during a field survey was much smaller for them than in the case of an ordinary field campaign in an unknown area. The fact that the aerial photo-based erosion figures for our study areas tend to be somewhat lower than the figures reported by Vandaele *et al.* (1996b) indicates the need to use a correction factor.

DISCUSSION

Table VII lists the advantages and drawbacks of both field surveys and aerial photos in assessing ephemeral gully erosion. One of the main advantages of using aerial photos is the time-saving aspect of this technique

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Table VII. Advantages and drawbacks related with the use of both high-altitude (stereo) aerial photos and field survey for the assessment of ephemeral gullies

Aerial photo	Field survey
Advantages	*Advantages*
• Time saving compared to field survey	• High accuracy is possible
• Possible to go back in time	• A wide range of parameters can be measured (e.g. depth, width, length, slope)
• Data can be derived over a more extended work period	• No difficulties with defining a gully
• Whole area looked through (no omissions)	• Continuous monitoring possible
• Easily to obtain	
• Reasonable prices	
Drawbacks	*Drawbacks*
• Small gullies are invisible	• Time demanding
• Gullies located in linear landscape elements are easily overlooked	• Gullies entirely located within a tall crop-covered field are easily overlooked
• Length is the only parameter that can easily be determined from a photograph	• Ephemeral gullies are only visible for a short period of time (till next tillage pass); data need to be collected within restricted work period
• Confusion between gullies and other linear features (e.g. path, furrow) is possible	
• Photos not always taken at the most suitable time of the year	

compared to field surveys. Based on our experience, assessing ephemeral gully erosion through field survey requires two persons during one day to cover an area of about 2 km^2. When aerial photographs are used, one person can easily cover 40 km^2 a day (i.e. two standard aerial photos with a scale of 1:21 000 a day). These figures are based on experiences for average rainfall events in central Belgium. When the intensity of the rainfall event and consequently of the gullying increases, the discrepancy between time required for each of the methods increases too. The second advantage of aerial photographs is that they permit the ephemeral gully erosion survey to be extended in time. Aerial photos are the only possible tool to assess ephemeral gully erosion rates over the last decades. Especially for studies dealing with the evolution of ephemeral gully erosion over time or studies dealing with the sensitivity of certain areas to ephemeral gullying, HASAP can be of great help. The only alternative for this kind of study is to set up a long-lasting (20 years or more) field monitoring campaign. Another advantage of using HASAP for ephemeral gully assessment is the fact that the survey can be organized systematically and that data can be derived over a more extended work period. The chance of omitting part of the study area is certainly decreased compared to field work, where main roads, hedges, streams and other such hindrances often make it difficult to go from one part of the study area to another. The fact that this kind of standard aerial photo is quite easy to obtain at a fairly low price, can also be mentioned as an advantage of the technique.

There are disadvantages related to the use of HASAP. First, HASAP are not always taken at the most suitable time of the year. Mean gully erosion values observed from HASAP will therefore be an underestimate. Secondly, the accuracy of an ephemeral gully erosion survey from HASAP is limited. It is physically impossible to observe gullies which are too small or which cannot be distinguished from their surroundings. Table II shows that both field work and aerial photographs generate an error of about 25 per cent compared to the best possible estimate of total ephemeral gully length. But the large difference between both methods is that the error related to HASAP is physically induced, while the error from the field survey is human induced and can therefore be avoided. The potential accuracy of a field survey is higher than the accuracy of HASAP, but to reach this high level of accuracy extra time will be needed, which may result in a negative cost/benefit balance. To overcome the accuracy limit partially, a correction factor (C) has been proposed. This correction factor accounts for the fraction of ephemeral gullies that cannot be seen on the aerial photos because (1) they are too small or (2) they are located in linear landscape features. This fraction

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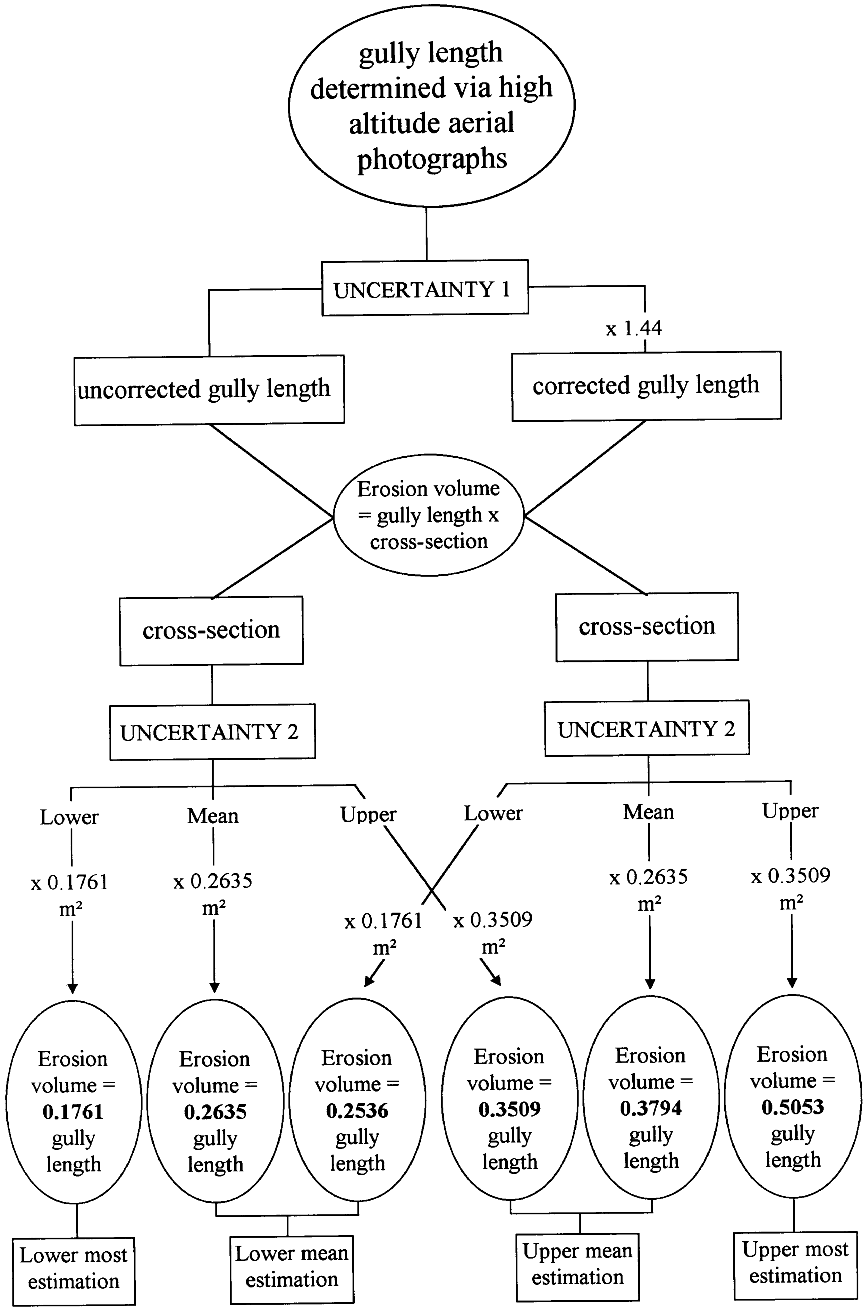

Figure 6. Illustration of the uncertainty (sources and levels) throughout the determination of ephemeral gully erosion volumes, based on data from high-altitude stereo aerial photographs

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of invisible gullies will, of course, vary through space and time and therefore applying the correction factor (*C*) introduces uncertainty to the results (Figure 6). One can choose to work with the uncorrected values, knowing that the obtained result is certainly an underestimate. Others may prefer to correct the measured gully length for the invisible gullies, knowing that the result is not exact, but is close to reality. A second source of uncertainty occurs when translating the observed gully lengths to erosion volumes (Figure 6). Cross-sectional data are obtained during a field survey in an area that is in every sense similar to the study areas of the HASAP, but again the obtained values are only indicative. Therefore lower, mean and upper average cross-section values are given. Superposition of both sources of uncertainty leads to a rather wide range in calculated erosion volumes (Figure 6). There is a factor of 3 between the lowermost estimate and the uppermost estimate and a factor of 1·5 between the lower mean and the upper mean estimate. Although this may seem quite a large variation, it reflects perfectly the accuracy that can be obtained. Other ephemeral gully erosion assessing methods, such as field work, suggest a higher accuracy giving only one single result, but in fact this result is also merely indicative, while the corresponding error is unknown.

CONCLUSIONS

From this study, it can be stated that ephemeral gully erosion surveys based on aerial data certainly have great potential. The accuracy is limited, but attempts to overcome these limits are made, which leaves the choice of working with absolute minimum figures or with corrected values. The fact that the results of the ephemeral gully erosion surveys based on high-altitude stereo aerial photos fit reasonably well with the results of other surveys carried out in the Belgian loess belt, indicates that this technique yields reasonable results.

Apart from the use for erosion assessment, it is also worth mentioning that the information from the HASAP can be useful in modelling ephemeral gully erosion. As the length and the location of an ephemeral gully have to be known to run existing ephemeral gully erosion models (Poesen *et al.*, 1998), aerial photographs can be of great help in providing input data for these models. Also, when looking for appropriate areas to test an ephemeral gully erosion model, a sequential series of aerial photos can be very helpful to select areas which are prone to ephemeral gully erosion.

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